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TITLE: Gas Compressor with Drier and Radio Emission Controls

FIELD OF THE INVENTION

This invention relates to the compression of gases. More particularly, it relates to the compression of natural gas and/or hydrogen for use in vehicles propelled by such gases. Specifically, it relates to an apparatus and methods for removing moisture vapor as part of the compression procedure and separating removed moisture from contaminants therein. It also relates to minimizing the release of electromagnetic radiation.

BACKGROUND OF THE INVENTION

It is known to remove moisture from gas in order to store such gas for use in a motor vehicle. Moisture is also removed from compressed gases for a variety of other applications. Typically, during the gas compression cycle the gas being compressed is passed over a desiccant bed which effects the removal of moisture from the gas. Eventually, the desiccant bed will saturate. A moisture sensor may be employed to detect the amount of moisture present in the gas exiting the compressor, sensing when the measured moisture content at the output of the compressor rises beyond a permissible range, above an upper limit. Alternately, a drying bed may be employed for a predetermined period of time. In either case a regeneration stage for recharging the desiccant bed is eventually required.

The technology for drying gas streams is well established. It includes absorption and condensation methods and the use of membrane separation systems. Examples of these technologies, used separately and in

combination are United States patent Nos. 5,034,025; 5,071,451 and 5,240,472 as well as the prior art referred to therein.

Existing compressors of this type have employed 5 gas drying arrangements that operate on a continuous basis, using a two-bed system. Examples of this type of technology include US patent 6,117,211.

The present invention addresses the object of compressing natural gas with a reduced amount of moisture 10 being present in the compressed gas by employing gas drying arrangements that operate on a dis-continuous basis, using a single-bed system wherein the compression of gas is eventually interrupted to allow the system to effect regeneration.

15 In the treatment of gas streams, de-watering processes generate extracted water that may contain traces of contaminants originating from the principal stream. In the case of natural gas, these contaminants include hydrogen sulphide, sulphur dioxide and mercaptans. Disposal of water 20 containing contaminants of this type can be subject to environmental restraints.

The extracted water being produced cannot be released locally into the environment because of the contaminants present therein. Apart from issues relating to 25 hazards, even trace smells of organic or sulphurous components from a natural gas stream would suggest to a consumer that a leak existed in the compressor system.

It is an object of this invention to address the 30 convenient disposal of separated water under these circumstances.

It is a further object of this invention to minimize the release of electromagnetic radiation during operation of the compressor system.

The invention in its general form will first be 5 described, and then its implementation in terms of specific embodiments will be detailed with reference to the drawings following hereafter. These embodiments are intended to demonstrate the principle of the invention, and the manner of its implementation. The invention in its broadest and 10 more specific forms will then be further described, and defined, in each of the individual claims which conclude this Specification.

#### SUMMARY OF THE INVENTION

15 According to the present invention in one aspect, a compressor for a gas which normally operates on a gas compression cycle is provided with a gas drier stage comprising a single desiccant bed located in-line with the flow of gas passing through the compressor during the gas 20 compression cycle. Also located in-line with such gas flow is a condenser which, during the compression cycle, is inactive. The temperatures of the desiccant bed and condenser are both controllable, preferably by electrical means. During the compression cycle, such temperature 25 controls are preferably inactive. However, upon entering into a regeneration cycle, the gas bed is heated and the condenser is cooled.

During the regeneration cycle arising from activation of a valve means, gas trapped within the 30 compressor, desiccant bed and condenser is redirected from the outlet of the compressor for circulation in a closed

loop as a recirculating gas flow through the compressor, with at least a portion of such recirculating gas passing through the dessicant bed and condenser. This permits water evolved from the desiccant bed to be carried by the 5 recirculating gas to the condenser where it condenses due to the low temperature condition maintained within the condenser by the temperature control means.

More specifically, in a preferred embodiment the outlet from the compressor is connected through an 10 electronically controlled valve to the delivery line which carries compressed gas off to a storage reservoir during the compression cycle. When the compressor ceases operating in compression mode, the electronically controlled delivery valve switches the flow of gas from the delivery line into 15 the interior volume of a casing cavity for the compressor. The compressor draws its input from the casing cavity.

The resulting drop of pressure in the delivery line causes a check valve at the external reservoir, which contains high pressure gas, to close. The compressed gas 20 trapped in the delivery line then "blows down" into the interior volume of the casing, producing a pressure condition that is moderately elevated above that of the supply line pressure eg 30-60 psi. The check valve at the supply line inlet to the interior volume then closes as the 25 source gas pressure is only of the order of 0.2 to 0.5 psi.

With output of the compressor redirected into the casing volume, the trapped gas is now capable of circulating in a closed loop through the compressor, desiccant bed, condenser, and casing volume with the trapped gas serving as

a sweep gas for regenerating the dessicant bed. Circulation of the gas within this closed loop is effected at a low gas flow rate so that the circulating gas passing through the condenser is substantially, preferably fully, chilled when 5 it exits the condenser. This maximizes the efficiency of transferring moisture from the desiccant bed to the condenser as a preferred mode of operation.

Circulation may be effected at a low flow rate by reducing the speed of the compressor motor. Alternately, 10 one or more valve-controlled bypass lines may divert a portion of the circulating gas around the dessicant bed, and/or the condenser, allowing only a limited amount of gas flow through these components. The permitted flow rate over the bed, established by the valve or by other flow-limiting 15 means, is set so as to be commensurate with the condensation of vapor from such gas. This arrangement allows the system to operate with a fixed speed motor.

In the regeneration process water evolves from the desiccant bed, raising the moisture content of the 20 circulating gas. The desiccant bed is heated at this stage to enhance its release of moisture. The released water, in vapor form, is then carried by the gas flow to the condenser where it condenses due to the low temperature condition maintained within the condenser. Circulating gas exiting 25 the condenser leaves the condenser in a cooled, vapor saturated, condition. By the time the circulating gas reaches the heated desiccant bed, its temperature has been raised and the gas is no longer vapor saturated. The heated

circulating gas is therefore able to absorb further moisture from the desiccant bed as it passes over such bed.

In order to dispose of water condensing within the condenser such water may simply be collected. However, to 5 achieve extended, stand-alone operation, the condensed water is directed, preferably flowing under gravity, into contact with a semi-permeable membrane which allows the water to evaporate. At the same time, aromatic compounds present within the condensate are retained by the membrane within 10 the condenser. To enhance the rate of evaporation and flow of water through the semi-permeable membrane, an external fan and optional heater element may be preferably positioned to circulate warm air past the membrane surface.

It is important to note that the condenser, 15 according to the invention, is located in-line with the gas flow during the compression cycle. This exposes the condenser and semipermeable membrane to an elevated pressure condition. In a preferred variant of the invention, the compressor is a multi-stage compressor and the desiccant bed 20 and condenser are positioned in-line between consecutive stages, preferably between the first and second stages of the compressor. Thus, although the condenser is exposed to an elevated pressure condition, this is not the final, maximum pressure produced by the compressor. Rather, it is 25 an intermediate pressure arising after only the first stage of compression.

This limitation on the pressure to which the condenser is exposed is particularly significant in the preferred embodiment of the invention wherein the condenser

is directly connected to a semi-permeable membrane through which condensed water is allowed to evaporate into the environment. Such membranes are only capable of withstanding a modest pressure differential. In the case of 5 a multistage compressor, the pressure developed between the first and second stage is not so high as to preclude use of such a semi-permeable membrane as a means to dispose of water condensate. A preferred form of membrane is tubing made of Hydroscopic Ion Exchange Membrane.

10           Thus, according to this preferred embodiment, condensed water accumulating in the condenser is directly, or eventually, disposed of by release into the environment, preferably through the semi-permeable membrane. Use of such a membrane ensures separation and retention of complex 15 odorous molecules that may be present in the water condensate, with only pure water being released into the environment.

Once the desiccant bed has been recharged, heating for the bed is terminated. As well, chilling of the 20 condenser and heating for the semi-permeable membrane, if employed, are terminated. Thereafter the valve means is actuated to reconnect the outlet stage of the compressor to the delivery line. The compressor motor is then speeded up to resume the compression cycle if it has been slowed down, 25 and the inlet to the supply line automatically reopens. Alternately, if a fixed speed motor is employed, the bypass lines is/are closed-off allowing the regular compression cycle to resume.

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In a further preferred variant, the compressor is 10 contained within a sealed metal casing. Supply gas enters the interior volume of this casing through a check valve and is drawn into the compressor from the crank-portion of this interior volume. Also located within the casing is the motor, preferably a variable speed motor, and preferably 15 control circuitry for delivering current to the motor. In these preferred scenarios, the motor is an alternating current induction motor, and in the variable speed situation the control circuitry produces an alternating current of varying frequency, whereby the speed of the motor is varied 20 in accordance with system requirements.

It is a further preferred feature of the invention that not only is the electrical motor operating the compressor mechanism contained within the same casing as the compressor, but also the control circuitry for delivering 25 power to the motor is contained within the casing. An advantageous result achieved by this arrangement is that electromagnetic emissions arising from current being

delivered from the motor controller to the motor are confined within the metallic casing.

The control circuitry, which may deliver current at 360 volts DC to the motor, is itself provided with 5 current through a sealed penetration of the casing wall. The motor control circuitry operates to create alternating current having a frequency of on the order 60 Hz but with multiple harmonics. The electrical power delivered to the motor provides current, at a typical maximum level, of on 10 the order of 8 to 10 amps. The electromagnetic radiation from the wiring extending between the control circuitry of the motor carrying a such current at such frequencies is a source of electromagnetic radiation. By confining this wiring to within the metallic casing, electromagnetic 15 radiation from this source is shielded from entering into the environment.

On start-up, low motor speeds are preferably adopted to reduce otherwise high start-up current drains on the electrical supply system. This enables the unit to 20 operate off of a standard household voltage, e.g. 110-120 volt, moderately fused electrical supply system. After start-up, initial compression can be effected with a high motor speed. Once higher pressures have been established in the motor vehicle fuel reservoir or other delivery 25 receptacle, the motor speed is reduced in order to moderate ring wear and limit power consumption. This procedure is especially suited to oil-less compressors as the wear rate of the sealing rings within the compressor cylinders of such units increases when the compressor system is operated at 30 high speed against a high-back pressure.

## SUMMARY OF THE FIGURES

Figure 1 is a pictorial representation of a gaseous fuel motor vehicle parked in a garage having a home refueling appliance according to the invention mounted on 5 its inner wall.

Figure 2 is a schematic for the basic components of the appliance showing besides the motor and compressor, the desiccant bed, the main logic controller, the motor control circuitry and various sensors.

10 Figure 3 is a schematic variant of Figure 2 showing gas flow during the compression cycle.

Figure 4 is a schematic as in Figure 2 showing the basic flow diagram of the appliance during the regeneration cycle wherein the desiccant bed is recharged and the motor 15 speed is variable.

Figure 5 is a cross-sectional side view of the compressor/motor assembly within its immediate case and the drier components. This compressor casing contains the motor, a blow-down volume, and the motor control circuitry. 20 Also shown is an additional, outer case or ventilation shroud to contain cooling air flow.

Figure 6 is a detailed schematic cross-sectional front view of the drier, condenser, and semi-permeable membrane portions of Figure 2 with the semi-permeable 25 membrane in the form of a tube through which water condensate enters under gravity.

Figure 6A is a cross-sectional front view of the drier, condenser, and semi-permeable membrane portions of Figure 6 showing the semi-permeable membrane tube through

which water condensate evaporates in the presence of a heated airflow created by a fan.

Figure 7 is a detailed, close-up, cross-sectional side view of the semi permeable membrane of Figures 5 and 6a 5 showing airflow around the coiled tubing.

Figures 8A and 8B are schematics as in Figure 2 showing the basic flow diagram of the appliance during the regeneration cycle wherein the motor speed is fixed and the drier-condenser has a bypass line that can divert flow past 10 the drier-condenser by switching flow into the circulating loop or to the casing cavity, or both, to permit a reduced gas flow rate to occur within the condenser.

## 15 DESCRIPTION OF THE PREFERRED EMBODIMENT

In Figure 1 the home refueling appliance 1 is shown mounted on a garage wall with the high-pressure discharge or delivery hose 2 connected to a car, the inlet or supply hose 3 providing a source of gas 6, and the 20 electrical cord 4 plugged into a standard household receptacle.

Figure 2 schematically depicts the unit operating in compression mode. In Figure 2 line gas 6 which may contain contaminants 8, enters the interior volume 14 of the 25 casing 26 from which it drawn into the first of a series of four

compression stages 28, 32, 33, 34 of compressor 5. The line gas 6, which typically has a pressure of between 0.2 and 0.5 psi is drawn into the interior volume 14 by the suction

created by the first compression stage 28. A line gas pressure sensor 21 detects the line gas pressure, providing a signal to the main logic controller 46.

On leaving the first stage 28, the gas 6 passes through 5 a desiccant bed 7 contained within an absorption chamber 29. This bed of desiccant material 7, such as activated alumina or zeolite, adsorbs the moisture in the gas 6, including at least some of the contaminants 8. Upon exiting the absorption chamber 29, the dried gas continues into the 10 volume of a condenser 30 which is, at this stage, passive. Exiting the condenser 30 through conduit 55, the gas 6 proceeds to the next, second stage 32 of the compressor 5. The flow of gas in this compression cycle is shown in Figure 3.

15 As shown in Figure 4, and in greater detail in Figures 6 and 6A, the desiccant 7 is regenerated by being exposed to a sweep gas 13 originating from the gas stream trapped in the compressor 5, motor 27, desiccant bed 7 and condenser 30 when the compression cycle is terminated. As 20 shown in Figure 4 the sweep gas 13 is drawn at a reduced flow rate through the absorbent bed 7, optionally by the slow speed operation of the change to motor 27. Moisture in the adsorbent bed 7 is encouraged to vaporize into the sweep gas 13 by its dry condition, as described further 25 below, by its pressure and the by the additional supply of heating to the absorbent bed 7.

Upon exiting the bed 7 the gas flows into condenser 30 which contains a heat-exchange surface. This heat-exchange surface is preferably cooled by an electrical-

actuated cooling block 53 operating on the basis of the Peltier effect.

Cooled, circulating sweep gas 13, which has now been de-moisturized in the condenser 30, then passes into a return 5 conduit 55 that leads to the second stage 32 of the compressor. The slow operation of the motor 27 and compressor 5 causes this sweep gas 13 to circulate endlessly until the regeneration cycle is terminated.

To speed the regeneration process and assist in 10 recovery of the water subsequently, a thermostatically controlled electrical element 52 warms the desiccant 7. The warmed, moisturized sweep gas more effectively releases moisture as it passes through the condenser 30.

As shown in Figures 2, and 6 liquified water 54 15 accumulates in the bottom of the condenser 30 as a condensate, below the level of the return conduit 55 within the condenser. The condensed water 54 will contain some residual contaminants 8a. This water condensate 54, including residual contaminants 8a present therein, may be 20 simply accumulated and collected or it may then be passed to a separation chamber preferably in the form of tubing 31 that has walls formed of a semi-permeable membrane 61. The semi-permeable membrane 61 allows only the penetration of water as the permeate. On the other side of the membrane 25 61, water diffusing therethrough evaporates. This process may be accelerated by an airflow originating from a fan 42. In this case the shroud 43 serves to duct a constant air flow over the membrane 61. Optionally the air flow in the

vicinity of the membrane may be heated by a membrane heater 56.

The circulating airflow 60 from the fan 42 may also be used to cool the condenser 30, preferably using separate ducting (not shown).

5 As water diffuses through the membrane 61, some contaminants 8a may accumulate on the interior surface of the

membrane 61. Eventually, the rate of diffusion may drop to a level where the membrane 61 must be cleaned or replaced.

10 In the foregoing description the semi-permeable membrane 61 could be in the form of a plate fitted as part of a wall of a separation chamber. Figures 6 and 7 show a preferred variant in which the semi-permeable membrane is shown as a tube 31. This tube 31 is preferably has a wall 15 formed of semi-permeable hydroscopic ion exchange membrane material. Membranes in the form of tubes made of modified Teflon(TM) have been found suitable for this application, showing life-times of practical duration.

It is noted that the absorbent chamber 29 and 20 condenser 30 are contained within the high pressure zone of the compressor 5, between the first stage 28 and the second stage 32. The pressure in this zone is only on order of 200 psi during the compression cycle. In fact, this pressure level enhances the gas drying effect. It has been found 25 that, at these pressure levels, the semi-permeable membrane 61 in tubing format can extend outside this pressurized zone, relying on secure couplings 57 to seal the connection between the tubing 31 and the condenser chamber 30. The use of the multistage compressor especially facilitates this 30 arrangement.

Further components as shown in Figure 2 include an inlet filter 22, a high pressure transducer 24, a

pressure relief valve 25 leading to a vent opening 50, a burst disc 35 in the fourth stage 34 to relieve excessive over-pressure, an in-line breakaway connector 36, the vehicle connection nozzle 38, a gas leak-detecting sensor 5 39, an air flow sensor 40, and an ambient air temperature sensor 41.

In Figures 8A and 8B a fixed speed motor variant is shown wherein a bypass line 60 or 60A is opened by valve 61 actuated by the main logic controller 46 during 10 regeneration. Due to this bypass, the sweep gas 13 passes through the desiccant material 7 and condenser 30 at a preferred flow rate. The amount of sweep gas 13 allowed by valve 61 and associated flow-limiting means to pass through this regeneration branch is set to maximize the efficiency 15 of the vapor evaporation and condensation process. Recirculating gas 13 is either diverted to the second stage 32 through bypass line 60, or to the casing volume 14 through bypass line 60A, or both bypass lines may be used in combination.

20 Referring to Figure 2, the compressor 5, motor 27 and motor control circuitry 45 are all located within the casing 26, (counting the compressor block as part of the casing), which is in turn, surrounded by an outer shroud 43. According to one variant of the invention the electronic 25 motor controller 45, which supplies current to the electrical motor 27, is preferably located within the totally contained environment of the motor/compressor assembly. This sealed environment is provided by the same metal casing 26 that surrounds the motor and compressor 30 parts. The motor control circuitry 45 is, in particular, located in the blow-down volume 14, sealed entirely within

the casing 26. The metallic wall of the casing 26 acts as heat sink for the heat produced by the motor control circuitry 45 and as a shield for outgoing electromagnetic emissions arising from wiring extending between the motor 27 and motor controller 45.

As shown in Figure 2, the main logic controller 46, fed power from a power supply 47, is able to activate the motor 27, and govern its speed in the variable speed version, through motor control circuitry 45. Signals 10 between the main logic controller 46 and motor control circuitry 45 penetrate the casing 26 at a sealed entry point 44. The command logic circuitry 46 sends and receives commands and data through digitally encoded signals transmitted along optical fibers. This minimizes the 15 electrical penetrations made into the interior 14 of the metal cavity of the casing 26 which contains natural gas in a slightly pressurized condition.

#### CONCLUSION

20 The above disclosed embodiments are only exemplary. The invention in its broadest, and more specific aspects, is further described and defined in the claims which now follow.

These claims, and the language used therein, are 25 to be understood in terms of the variants of the invention which have been described. They are not to be restricted to such variants, but are to be read as covering the full scope of the invention as is implicit within the invention and the disclosure that has been provided herein.